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Classification System for Carbohydrates

CONVENTIONAL CHEMICAL NAMES of carbohydrates are cumbersome and are not always sufficiently distinctive for convenient structural classification. To overcome these disadvantages, H. S. Isbell of the National Bureau of Standards has developed a simple classification system [1] in which each carbohydrate is assigned a code number that defines its structure and configuration. By inspection of the code numbers, or by a punched-card technique, related carbohydrate derivatives can be selected readily from a heterogeneous collection.

The numerical classification system was worked out in connection with a program sponsored at the Bureau by the Office of Naval Research, for investigation of the structure, configuration, and ring conformation of the sugars and their derivatives by infrared absorption measurements. Although devised primarily for comparing infrared spectra, the system can be used for classifying structurally related carbohydrates for a variety of purposes. It should be useful to research workers who need to assemble lists of structurally related compounds for any reason.

For classification of simple carbohydrates, a primary code number of 6 or 7 digits is used. Additional digits are sometimes required for more complex structures. A decimal point is inserted after the second digit in the primary code number to separate figures that provide broad generic classification from those that show definite structure.

The first digit in the code number divides the carbohydrates into groups of increasing complexity. For example, 1 indicates a monosaccharide; 2, a disaccharide, etc. The second digit shows substitution on the polyol structure. When half or more of the hydroxyls are free, the classification number is 0; when more than half of the hydroxyls are substituted, the number corresponds to the substituent present in predominating amount. If two classifications are possible, the one with the lower number is used.

The first digit to the right of the decimal point defines the skeleton of the fundamental carbon chain; and the next digit, the configuration of the main structural unit. No distinction is made between D and L modifications because enantiomorphic substances give like infrared absorption spectra.

The third digit to the right of the decimal represents the characteristic structure of the substance. Products containing anomeric forms in equilibrium, such as amorphous sugars and materials not subject to specific classification, are represented by 0; pyranose and

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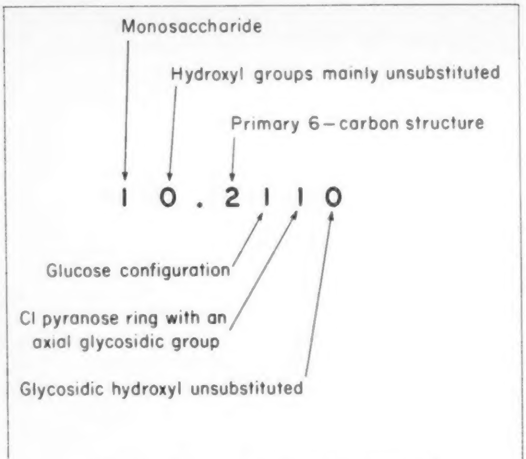


CODING OF α—D—GLUCOPYRANOSE

furanose structures by 1 to 6; glycitols by 7; open-chain aldehyde and ketone derivatives by 8; and aldonic acids by 9 regardless of whether they are present as the acid, salt, ester, amide, or lactone.

The fourth and fifth positions to the right of the decimal show the character of the main functional group, usually the glycosidic group. Because there are more than 10 common substituents, two spaces are allowed for this information.

The coding of α-D-glucopyranose may serve as an example. This compound is given the code number 10.2110. Reading from left to right, 1 shows that the substance is a monosaccharide; 0, that the hydroxyl groups are predominantly unsubstituted; 2, that it has a primary 6-carbon structure; 1, that it has the glucose configuration; 1, that it has a C1 pyronose ring with an axial glycosidic group; and 0, that the glycosidic hydroxyl is not substituted.

Similarly, the code numbers for all α-D-glucopyranose structures have the .211 sequence. That is, each structural grouping has a characteristic sequence of numbers. Hence, by inspection of the numbers, or by punched-card technique, groups of structurally and configurationally related carbohydrate derivatives can be readily selected.

Various schemes are used for more complicated substances. For example, a partially substituted structure is shown by a group of numbers to the right of the primary code number. The first number or numbers, given in parentheses, show the position of substitution; the next number defines the substituent. Several substituents can be listed consecutively. Auxiliary or additional structures are treated like substituents. The main functional group is considered first, and the second (auxiliary structure) is shown by suitable numbers following its position in parentheses.

[1] *For further details, see* System for classification of structurally related carbohydrates, *by Horace S. Isbell, J. Research NBS* **57**, *171 (1956) RP2707.*

Radiation Protection Group Appoints New Executive Committee

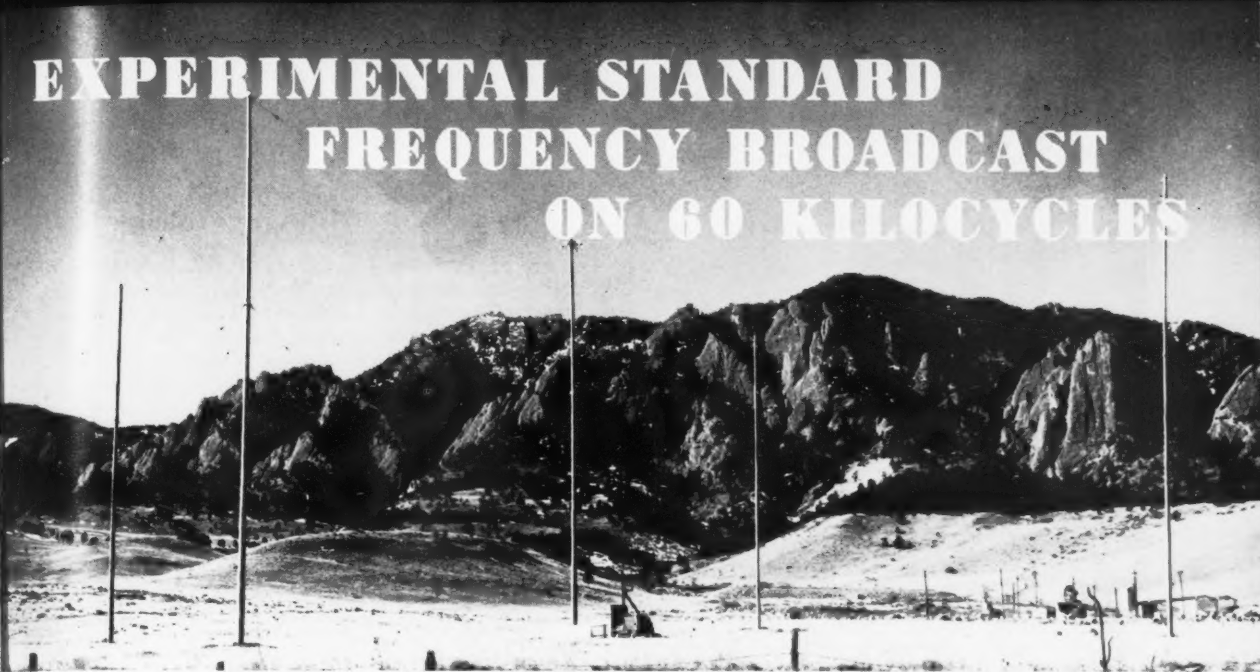
THE NATIONAL COMMITTEE on Radiation Protection and Measurements (NCRP) has announced a change in the membership of its executive committee. Within the operating procedures of the NCRP, the executive committee is responsible for the broad policies and direction of the work of the Committee, and its membership is selected to provide as broad representation as possible of the many disciplines that are involved in the philosophy and development of radiation protection.

Sponsored by the Bureau, the NCRP is an advisory group of experts in various phases of the radiation field, and is made up of representatives from 15 professional and governmental organizations concerned with the manufacture and use of radiation generating equipment and with the associated problems of health and safety. The recommendations of the Committee are published by the U. S. Government Printing Office in the NBS Handbook series.[1]

The members of the new executive committee and their institutional affiliations are as follows: L. S. Taylor, Chairman, Atomic and Radiation Physics Division, National Bureau of Standards; E. C. Barnes, Industrial Hygiene Department, Westinghouse Electric Corporation; C. B. Braestrup, Physics Laboratory, Francis Delafield Hospital (City of New York Department of Hospitals); C. L. Dunham, Division of Biology and Medicine, U. S. Atomic Energy Commission; J. Bentley Glass, Department of Biology, Johns Hopkins University; H. M. Parker, Hanford Laboratories, General Electric Company; Clinton Powell, Division of Special Health Services, U. S. Public Health Service; Robert S. Stone, Medical Center, University of California; and Shields Warren, Cancer Research Institute, New England Deaconess Hospital.

[1] *For a preliminary statement of the Committee's most recent recommendations, see* Maximum permissible radiation exposure to man, *NBS Tech. News Bul.* **41**, *17 (Feb. 1957).*

EXPERIMENTAL STANDARD FREQUENCY BROADCAST ON 60 KILOCYCLES



Antenna structural used by the Bureau for experimental standard frequency broadcast at 60 kc. The location is about 1 mile east of the Flatiron Mountains, a part of the front range of the Rocky Mountains. Five 125-foot poles, one on each corner of a square and one in the center, support the wires of the antenna. Tuning house is near the center pole.

AN EXPERIMENTAL 60-kc standard frequency broadcast, begun July 1, 1956, at the Boulder (Colo.) Laboratories of the Bureau, is opening up several interesting applications, some of which are already in use. A. H. Morgan, Chief of the Radio Broadcast Service Section of the NBS Radio Standards Laboratory, is supervising the experiment.

The Bureau has been broadcasting standard frequencies since 1923, when radio was in its infancy and very few people owned radio receivers. Through the years higher power and more frequencies have been added until at present the NBS standard frequency broadcasts are on six high frequencies (2.5, 5, 10, 15, 20, and 25 Mc) at WWV, Beltsville, Maryland; and on three (5, 10, and 15 Mc) at WWVH, Maui, Territory of Hawaii. Up to 10 kw are radiated on some of the frequencies. Specialized radio receivers for these broadcasts have been commercially available for many years.

Measurements by the Boulder Laboratories and others have revealed that the regular standard broadcasts at high frequency (HF) are subject to changes in frequency as they travel away from the transmitting antenna. These changes are caused by disturbances in the propagation medium, and the errors introduced may at times amount to ± 3 parts in 10^7. This is sufficient to make these HF broadcasts unsuitable for many applications, e. g., rapid assessment of drift in the manufacture of high-precision quartz resonators, intercomparison of frequency standards, and accurate time measurement or synchronization of events at two or more locations which may be separated by thousands of miles. Two techniques are now available for precise frequency calibration, but both have limitations. One such technique, employing time comparisons, requires expensive terminal apparatus and a measurement time that extends over 1 to 10 days or even longer. The other makes use of a ground wave near the transmitter. This introduces an error in propagation of less than 1 part in 10^{11}, but is useful only to about 20 miles from the transmitter. At distances of greater than 20 miles the skywave must be used, and calibrations made by means of this wave are not adeqate for the ever increasing precision required by an expanding science and technology.

To meet this urgent situation, W. D. George, Acting Chief, Radio Standards Laboratory, initiated a plan to begin the experimental broadcasts at several low or very low frequencies. The 60-kc frequency is being put into use first under the call sign, KK2XEI.

The principal reason for studying standard frequency broadcasts at frequencies below about 100 kc is to determine a practical method whereby the radio propagation errors are minimized and users may accomplish high-accuracy frequency comparisons in a shorter measurement time. Users also need a better time or phase reference to precisely measure the time between events that happen in relatively short intervals, for example, in measuring the velocity of rapidly moving waves or objects.

Several investigators, among them Professor J. A. Pierce at Harvard University, have shown that for frequencies below 100 kc and for distances of 5,000 km and greater, it requires only about 10 min to compare local frequencies with standard frequency transmissions to within 1 part in 10^9. This is an

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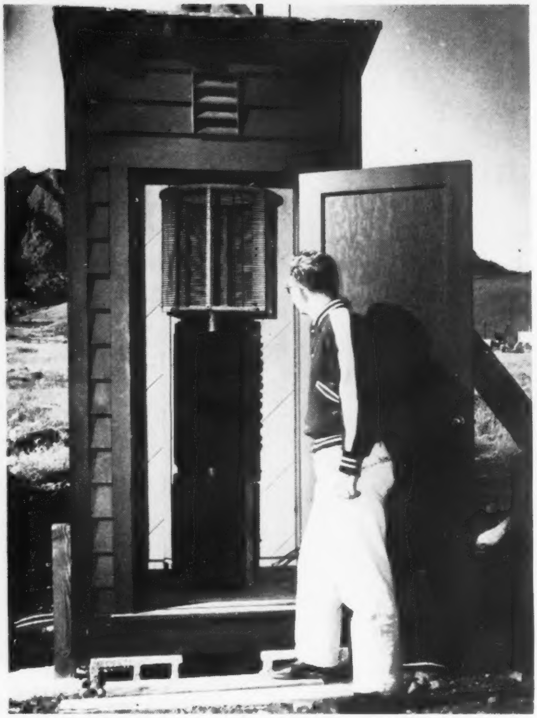
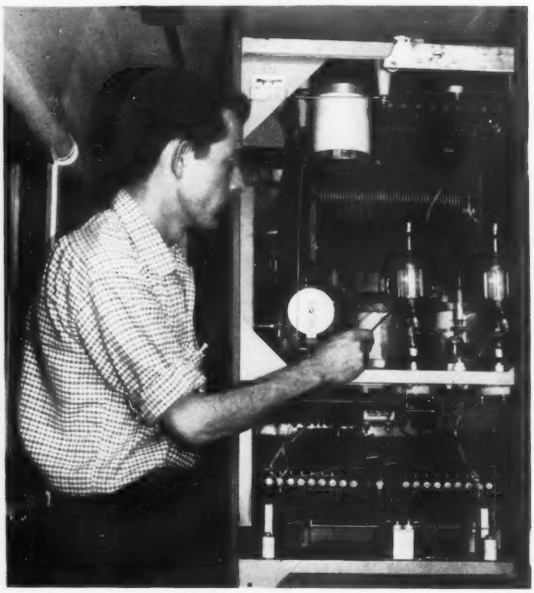


Above: **Interior of the tuning house near the antenna base, showing the tuning coils used in efficiently transferring power from the transmitter (about 3,000 ft away) via an overhead transmission line to the antenna.**

Below: **John Milton of the NBS Boulder Laboratories points to a 2,000-w output amplifier in the experimental 60-kc transmitter. Control frequency from the national standard is fed to the transmitter via a 1,500-ft transmission line.**



improvement of more than 100 over what can be obtained at HF. Professor Pierce has carefully determined that a high-accuracy standard frequency service can be given for all the world on a single very low frequency from a single high-power transmitter.[1]

The experimental broadcast on 60 kc, although on low power, has already presented several intriguing possibilities. With the cooperation of Professor Pierce, it has been possible to compare the NBS primary frequency standard, broadcast on 60 kc, with the British standard which is broadcast on 16 kc and 60 kc, to an accuracy of comparison that is better than 2 parts in 1 billion. This has been done almost continuously since the broadcasts began last July. Results for the month of January 1957 are shown in table 1. Regular measurements on the 60-kc broadcast are now being made by several groups in the eastern United States.

The most challenging project will be an attempt to compare the Boulder Laboratories' atomic-frequency standard, which is much more stable than 1 part in 10^9, with those in England and elsewhere. This will be undertaken as soon as possible. It is estimated that an accuracy of comparison of better than 1 part in 1 billion can be attained.

Tests with the experimental low-frequency standard broadcast will provide information not only on the ultimate stability of the received waves, but on possible ways of improving the standard frequency broadcast services. A high-power VLF station would be very expensive but probably less so than a network of HF or VHF stations which would be needed to give a frequency and phase standard of high accuracy at all times and places on the earth.

[1] Intercontinental frequency comparison by VLF radio transmission (*Proc. IRE, Special VLF issue to be published in 1957*).

TABLE 1. *Comparisons of 60-kc experimental broadcast, Station KK2XEI*

(Values given are parts in 10^9)

Date (1957)	Versus NBS Standard at Boulder	Versus GBR measurements made at Cruft Lab.	Versus WWV (average over 10 days) as received at Boulder	Versus WWV as received at Cruft Lab.
Jan. 2	−0.3	−1.4	+1.0	+2.2
3	+0.2	−2.1	+1.5	+2.2
4	+0.3	−2.3	+1.7	+0.7
7	+0.7	-----	+2.3	-----
8	−0.1	-----	+1.5	-----
9	−0.3	−3.7	+1.4	+0.4
10	+0.3	-----	+2.1	-----
11	+0.5	−2.4	+2.3	−0.9
14	0	−1.8	+2.0	+1.0
15	+0.1	−1.4	+2.1	+1.6
16	0	−1.1	+2.2	+1.1
17	+0.1	−0.8	+2.4	+2.6
18	0	−1.5	+2.3	+2.8
21	+0.8	−1.4	+2.7	+2.6
22	+0.3	−0.5	+2.1	+1.7
23	+0.4	−0.3	+2.4	+2.4
24	+0.5	−0.9	+2.4	+2.9
25	+0.1	−1.8	+2.0	-----
28	−0.3	−2.4	+1.4	-----
29	+0.1	−1.9	+1.8	-----
30	−0.2	−2.9	+1.4	+1.7
31	−0.2	−2.4	+1.4	+1.2
Feb. 1	0	−2.6	+1.5	+1.7

SOLAR FURNACE

A SOLAR FURNACE that generates temperatures two-thirds as hot as the surface of the sun has recently been acquired by the Bureau as a new research facility in the high-temperature field. Bureau scientists are now using the furnace to produce temperatures up to 3,500° C to melt refractory materials in a controlled environment free of contaminating agents. Investigations at high temperatures carried out with the aid of the solar furnace should result in better temperature-resistant materials to withstand the extreme conditions found in atomic reactors, aircraft engines, and guided missiles.

New or improved refractories—that is, materials that can withstand very high temperatures for long periods of time—are continually being developed by industry, and new applications are being found for these products. Consequently, knowledge of the properties of these materials—melting points, strength at high temperatures, etc.—is urgently needed. Investigations in this field should supply valuable engineering information to the user of refractories. High-temperature tungsten arc or carbon resistor furnaces have commonly been employed in the past for such studies, but with the disadvantage that the crucibles, electrodes, or resistors contaminate the reaction and give false indications. However, in a solar furnace, the material itself can be its own crucible, with consequent freedom from contamination.

The Bureau's solar furnace was converted from a surplus Army searchlight with a 5-ft diameter parabolic mirror. It collects the sun's rays and focuses them into an intensely hot spot only 1/4 in. in diameter. Heating occurs only at this small spot, and the experiment is carried out here. This area can be isolated by closed glass tubing, which can be evacuated or filled with gas of the experimenter's choice. The glass enclosure is not affected by the sun's rays because the image of the sun is unfocused where the light passes through the enclosure and no local heating of the glass results.

The curved mirror faces a flat mirror, about 8 ft square, which is directed at the sun and reflects the light into the solar furnace. This large, flat mirror, called a heliostat, is attached to a searchlight mount so that it can be turned to follow the sun through the sky as the earth turns on its axis. An assembly of photocells with appropriate electronic equipment controls the heliostat driving mechanism in response to the sun's apparent motion.

Besides study of the properties of refractory materials, the solar furnace can be used in the "zone refining" of oxides of zirconium, thorium, or uranium to produce extremely pure samples of those compounds. By means of the solar furnace it might even be possible to grow single crystals of these and similar materials for laboratory studies.

Solar energy furnace converted from U. S. Army surplus searchlight. The furnace can produce temperatures up to 3,500° C to melt refractory materials. Flat mirror (heliostat) at left collects light and reflects it into the parabolic mirror at right.

Training Program in Numerical Analysis

IN RESPONSE to the urgent need for training and research in numerical analysis, the Bureau and the National Science Foundation have undertaken a training program in numerical analysis for senior university staff. The aim is to give regular university staff members, heretofore specializing in fields other than numerical analysis, a training that will enable them to direct the operation of a university computing center and to organize training and research in numerical analysis at their own institutions.

The program recognizes that modern automatic equipment is not sufficient in itself for a computing program, and that explicit efforts are required to communicate the "know-how" that has been and is being developed, especially because little of this is available in published form. The program attacks the problem at its root, by training teachers of numerical analysis, individuals who can in turn become the nuclei of training programs of their own.

The program was given at the Bureau and occupies the whole of the second semester of the academic year 1956–1957 (February 11 to June 9). This period was chosen so that participants could become familiar with the details of their own computing equipment during the summer and be able to conduct courses in the academic year 1957–1958.

In order that each could receive individual attention, the number of participants was limited to twelve. Selections were made on the basis of qualifications of the individual and of the computational program of his institution by a committee approved by the Mathematics Division of the National Science Foundation. Grants are made to the parent institution of one-half the individual's salary and of the whole of his travel expenses and subsistence.

The program was under the general direction of John Todd, Chief of the NBS numerical analysis group, and assisting him were H. A. Antosiewicz, P. Davis, M. Newman, M. Marcus, and Ky Fan. Major contributions were also made by O. Taussky, F. Oberhettinger, and F. L. Alt. Detailed coding assistance with the Bureau's electronic computer, SEAC, was provided by members of the NBS computation laboratory under the direction of M. Abramowitz.

Demonstrating a sample problem on SEAC to participants in the NBS training program in numerical analysis. Sponsored by the National Science Foundation, the program is designed to train senior members of university mathematics faculties to supervise the operation of numerical analysis laboratories at their own institutions. *Left to right:* M. Newman, NBS; P. A. Clement, State College of Washington; Mary Lister, Pennsylvania State College; H. C. Griffith, Florida State University; F. R. Olson, University of Buffalo; C. L. Seebeck, Jr., University of Alabama; and H. W. Wicke, Sandia Corporation. Other participants, not shown here, are: R. F. Gabriel, Rutgers University; D. C. Lewis, Johns Hopkins University; O. W. Rechard, Washington State College; F. Scheid, Boston University; C. Spector, Jr., Ohio State University; and V. J. Varineau, University of Wyoming.

Although most of the instruction was given by NBS staff members, there were also guest lectures by specialists in various topics of numerical analysis. The list of guest lecturers includes H. Buckner, D. M. Young, A. Brauer, H. Cohn, J. W. Givens, M. Hall, Jr., S. C. Kleene, R. D. Richtmeyer, S. M. Ulam, and H. F. Weinberger. The Ramo-Wooldridge Corporation and the General Electric Company supported the program by sending speakers from their staffs.

Problems of Numerical Analysis

The marked increase in demand for the services of the numerical analyst is due mainly to the expanding use of large-scale automatic computers, of which there are now well over 1,000 in this country. The usual solutions to classical problems have been expressed in forms not necessarily suitable for automatic computers, and it is one task of the numerical analyst to re-examine the older methods in the light of the new

equipment. This examination includes classification and unification as well as detailed studies of special methods. Another task is the development of new methods for handling the old problems more efficiently. Work must be done, too, on entirely new problems raised by recent scientific developments even including the development of automatic computers themselves. Moreover, the field of numerical analysis is still in many respects undeveloped. In the rush to exploit the new high-speed computers, many ideas have been adopted on the basis of superficial plausibility or even, as it seems, on no basis at all.

A simple example may help to clarify the picture. The first solution of systems of linear algebraic equations that the schoolboy encounters is by the elimination method. A few years later he learns determinants and the solution by Cramer's rule, which is usually regarded as an improvement. From the point of view of the automatic computer, however, the primitive method is incomparably the better for systems involving even a moderate number of unknowns. The literature on this topic—which one might have thought closed a few years ago—has become enormous. Two volumes of the NBS Applied Mathematics Series have been devoted to it and a third is in press.[1] Numerical analysts have also devoted much attention to linear inequalities. These play an essential part in applications of linear programing and the theory of games of strategy, subjects that have developed only in the last 10 years.

Another—and very broad—field of research concerns the estimation of the effects produced by approximations. These approximations may arise from uncertainties in the initial data, from simplified assumptions introduced to make a problem tractable, or from the method of computing particular numerical values (rounding-off error, to mention the simplest case).

Finally, there is the question of just what kinds of numbers are computable at all—given the basic capabilities of the automatic computer. This question arose, as a matter of pure theory, before the realization of the modern automatic computer. In the hands of Turing and others, it led to important developments in logic and the foundations of mathematics. This theory is now being fed back into computing practice.

Older methods of numerical interpolation, differentiation, and integration designed for hand computation and desk machines, have provided starting points for some of the research in numerical analysis. Many of the numerical analyst's more powerful techniques, however, stem from developments in other branches of pure and applied mathematics—among others, from functional analysis, asymptotics, number theory, recursive functions, matrix theory, mathematical logic, and statistics. A good numerical analyst needs a sound training in classical mathematics, and some knowledge of the fields of science in which his problems arise, together with a thorough acquaintance with the equipment at his disposal. Incidentally, research in numerical analysis has repaid its debt to other branches of mathematics by contributing in turn to the solution of problems in these areas.

The NBS–NSF program surveyed the various topics indicated (as well as some of the administrative problems of a computing center) though not in an exhaustive manner, of course. However, participants who were specially attracted to a particular topic had ample time to talk with the program staff so that they could be brought up to date in the subject.

[1] *NBS Applied Mathematics Series 29,* Simultaneous linear equations and the determination of eigenvalues, *Proceedings of a symposium held on August 23–25, 1951, in Los Angeles, Calif. (1953) 126 pages, $1.50; NBS Applied Mathematics Series 39,* Contributions to the solution of systems of linear equations and the determination of eigenvalues *(1954) 139 pages, $2.00; NBS Applied Mathematics Series 49,* Further contributions to the solution of simultaneous linear equations and the determination of eigenvalues *(in press). Available from Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.*

Standard Samples and Reference Standards

A SECOND EDITION of NBS Circular 552, *Standard Samples and Reference Standards,* an up-to-date descriptive listing of the various standard samples issued by the Bureau, has recently been published.[1] It supersedes the first edition of Circular 552 which was issued in August 1954.

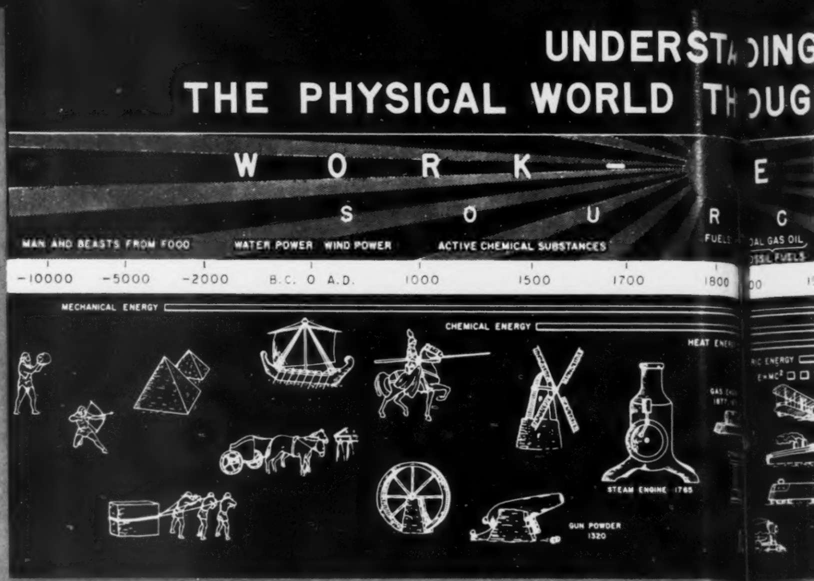
Besides the descriptive listing, the Circular includes a schedule of weights and fees and directions for ordering. Summary tables of analyses show the types of standards of composition that are presently available. Information on the current status of the various standards will be indicated in mimeographed inserts.

The NBS program on standard samples has been in existence almost since the organization of the Bureau. The first standards were prepared in 1905, and today over 550 different certified standard samples of chemicals, ores, ceramics, and metals are distributed by NBS. They are used in industrial and research laboratories to control manufacturing processes and to evaluate the accuracy of apparatus and equipment.

The standard samples are materials that have been carefully analyzed, or whose physical properties have been precisely determined, at the Bureau and other laboratories.

[1] Standard samples and reference standards, *NBS Circular 552 (second edition), 24 pages, can be obtained at 25 cents per copy from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. It is also available without charge to prospective purchasers of standard samples, upon request to the National Bureau of Standards, Washington 25, D. C. Foreign remittances must be in U. S. exchange and should include an additional one-fourth of the publication price to cover mailing costs.*

GUEST WEEK 1957



Students See Science in Action

NEARLY 6,000 high school students and their teachers visited the laboratories of the National Bureau of Standards during the Bureau's recent Guest Week, May 20–24. Through lectures, demonstrations, exhibits, and visits to individual laboratories, the students were given a general introduction to the world of science and the activities of a large research establishment. In the course of their visit, they saw a controlled demonstration of uranium fission, a solar furnace [1] that heats materals to 6,300° F, a new laboratory set up to study high-temperature materials, and a demonstration of recent NBS experiments [2] that showed the breakdown of the law of conservation of parity.

The Guest Week visitors were the first lay audience to witness an experimental demonstration of the storage of highly reactive molecular fragments, known as free radicals, at a temperature near absolute zero.[3] They saw the green glow emitted by nitrogen atoms quick-frozen at liquid helium temperature and the blue flashes they emit on recombining to form molecules. They were told that free radicals provide one of the most concentrated forms of chemical energy yet discovered.

Theme of the 1957 Guest Week was "Understanding the Physical World Through Measurement." Planned in cooperation with the U. S. Office of Education and the National Education Association, the program was designed to interest young people in science so that they may better understand the world of tomorrow. The student visitors were selected from science and mathematics classes of high schools within a 100-mile radius of Washington, D. C. The States of Delaware, Maryland, Pennsylvania, Virginia, and West Virginia were represented, as well as the District of Columbia.

The guests assembled in the High Voltage Laboratory, where they were welcomed by Dr. Allen V. Astin, NBS Director. They then witnessed a lecture-demonstration by Bureau scientists on man's historic struggle to harness and control the various forms of energy in the universe. The guests were also taken on guided tours involving the work of 21 laboratories.

Lecture-Demonstration

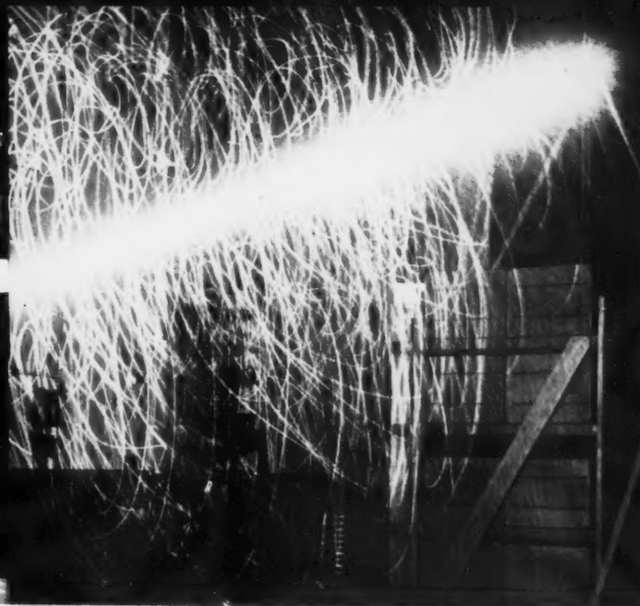
The lecture-demonstration began with prehistoric man, whose only source of energy was his own muscles, and traced the historical development of means for utilizing other energy sources from the steam engine to uranium fission. The important part played by physical measurement was illustrated by quantitative experiments duplicating the results of those important scientific discoveries that have opened up new sources of energy to mankind.

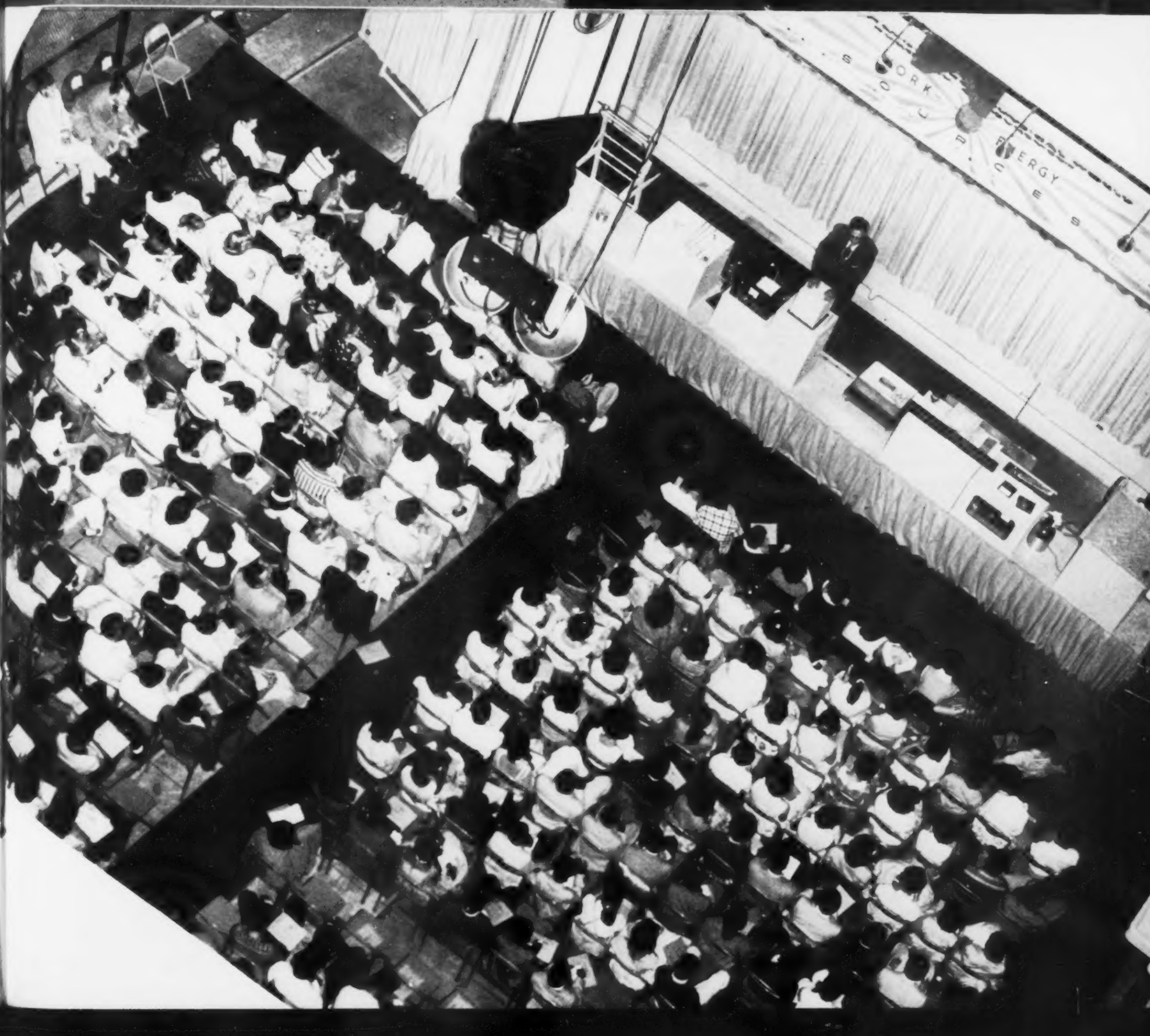
Through ancient and medieval times, man's supply of energy was limited to his own muscles, animal power, and wind and water power. The ultimate source of all this energy, of course, was the sun, which made plants grow food and warmed the earth, causing wind currents and rainfall.

Toward the close of the Middle Ages, man discovered that the chemical energy in gunpowder could be trans-

Right: NBS Director A. V. Astin welcomes high school students to the 1957 Guest Week program. A total of 6,000 students, selected from high schools in the District of Columbia and five neighboring States attended the week-long science exhibition. Dr. Astin described the functions of the Bureau, pointing out its contributions to industry and technology, and to the everyday life of the citizen, as well as to the progress of physical science. He then introduced leading NBS scientists who delivered a lecture-demonstration on man's search for energy sources from prehistoric days to the atomic age. Major advances in the conquest of energy were pictured in chronological order on the stage backdrop (above) which served as an outline for the lecture. Among the demonstrations were a small-scale experiment in nuclear fission and the first general exhibition of an experiment in the storage of free radicals, one of the most concentrated forms of chemical energy known. The lecture-demonstration, which took place in the High Voltage Laboratory, ended with a spectacular conversion of electrical energy into light and sound (above, right). This was accomplished by discharging an array of condensers through an iron wire, causing it to explode. Afterwards, students visited a number of laboratories where brief talks and demonstrations were presented on Bureau research in physics, chemistry, engineering, and applied mathematics.


MEASUREMENT
E N E R G Y
R C E S
RADIOACTIVE MINERALS
1800
1930
1940
1950
1957
HEAT ENERGY
ATOMIC ENERGY
ATOMIC REACTOR 1942
ATOMIC POWER PLANT 1952
A-BOMB 1945
H BOMB 1952
NUCLEAR FISSION 1939
CONTROLLED FUSION PROCESSES
NEW SOURCES OF ENERGY




ENERGY

formed into mechanical energy. However, it was not until about 200 years ago that he began to understand fully the equivalence of heat and mechanical energy. By this time the invention of the steam engine (in 1765) had suggested the possibility of an exact relationship between these two forms of energy, and measurement methods had been developed to the point where this relationship could be established.

With the determination of the mechanical equivalent of heat, a new era began as scientists sought other forms of energy and studied ways of transforming one form of energy into another. Coal, and later oil and gas—fossil fuels which the sun had stored in ages past—were discovered. These, it seemed, provided man with limitless supplies of energy to do his work.

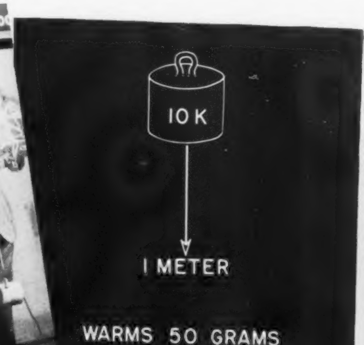
But after the invention of the electric dynamo and the gasoline engine, people began to use these new sources of energy so widely that the supplies of fossil fuels seemed to be facing imminent exhaustion. In the years preceding World War II, the outlook was not promising. Man's ultimate source of energy was still the sun, and solar energy stored on the earth was being used faster than it was being replaced.

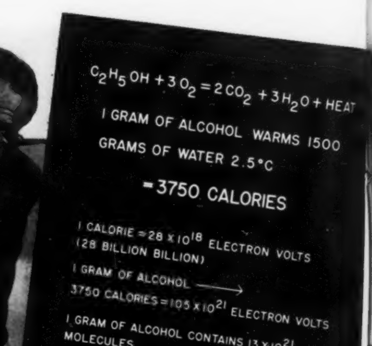
It now appears that man's eternal curiosity, directed to the accurate measurement of natural phonomena, may ultimately save him from this predicament. Radioactivity had been discovered many years before, and careful measurements had shown that during its lifetime 1 gram of radium releases approximately as much heat energy as one-half a ton of coal. Other measurements, of energy received from the sun, had shown that energy transformations of the type known up to this time could not possibly account for the amount of energy that the sun continues to provide. Searching for the key to this enormous energy output, scientists began to suspect that mass might be but another form of energy, and that if a way could be found for converting mass into energy, the world would have an inexhaustible energy supply. Early in this century Albert Einstein had proposed the now famous equation $E=MC^2$, postulating the equivalence of energy and matter, but for many years no one had found a way of actually transforming matter into energy.

Then, in 1939, came the discovery of nuclear fission, making possible the conversion of some of the mass in the nuclei of atoms into energy. In 1942 the first atomic reactor was put into operation, and the development of atomic power became a practical possibility. In 1952, the first nuclear fusion explosion was brought about, with a release of energy several hundred times as great as in the first A-bomb. Now, for the first time, man was able to duplicate the process by which mass is transformed into energy within the sun. The next problem he must solve is to control the energy from nuclear fusion so that it may be used to drive ships and to run electric power plants, as is now done with energy from nuclear fission. The students were told that one of them may perhaps make the discovery that will lead mankind to the next stage of harnessing the vast storehouse of energy in the universe.

The demonstrations included experiments illustrating transformations between potential and kinetic energy, and between mechanical, chemical, heat, and other forms of energy. For example, the Bureau's radiation balance [4] was used to measure the heat energy given off by radium in its disintegration. In another experiment the energy released by fission of uranium-235 atoms under neutron bombardment was shown on an oscillo-

***Below:* On this and the following page, are shown four of the demonstrations presented to students during the main lecture-demonstration, with charts containing relevant quantitative data. *Below, left:* A determination of the mechanical equivalent of heat. A. G. McNish, Consultant to the Director, has just cranked a 10 kilogram weight through a vertical distance of 1 meter. The weight was then permitted to fall, its motion being retarded by a small brakeshoe (upper right of frame) which is applied by R. D. Hunton, Associate Director for Physics. The mechanical potential energy of the weight is thus transformed into heat in the brake, and the heat in the brake is determined by immersing it in a known mass of water and measuring the rise in temperature. *Below, right:* Determining the heat of combustion of 100 proof ethyl alcohol. One gram of the alcohol has been poured onto a wick which is being lighted. The burning wick is moved upwards so that the flame burns within the lower part of the helical chimney that winds through the water in the beaker. In this way practically all of the heat generated is absorbed by the water, whose rise in temperature permits the heat to be measured in calories. The result, 3,750 calories, contrasts with the mere 25 calories stored in a 10 kilogram weight lifted through 1 meter.**





scope screen, where it could be compared with the much smaller energy released by the radioactive disintegration of the more common uranium-238 atoms. Storage of chemical energy was illustrated in the free radicals experiment.

Tour of Laboratories

In their tour of the Bureau, the young guests were taken to individual laboratories to see demonstrations of work in the following fields:

Radiation: Its Measurement and Effects. Nuclear radiation from radioactive sources is essential in medicine for treating patients and, in industry, for radiographic inspection of materials and for inducing changes in materials by irradiation. In military, civil defense, and atomic energy programs it is used for radiation instrument development and calibration.

The Bureau's recently constructed Gamma Ray Laboratory was designed for handling small radioactive sources. Here much of the radium preparations used in treating cancer are measured, and cobalt-60 sources are calibrated for use as secondary standards.

This laboratory also tests radiation detection instruments. For this purpose there are three large cobalt-60 sources shielded by lead under the floor of the laboratory's High Level Room. The instruments tested include Geiger counters, ionization chamber and crystal detectors, and personnel monitoring devices such as pocket dosimeters and film badges.

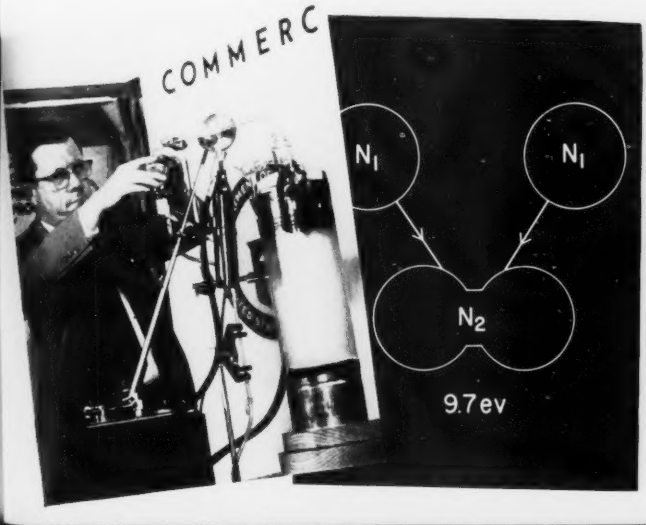
A recent addition provides a large cobalt-60 source in a 12-foot-deep pool of water for the study of changes in materials when irradiated at temperatures from −270° to +600°C. Thus far it has been used mainly to study effects of radiation on plastics and on the monomers from which they are made.

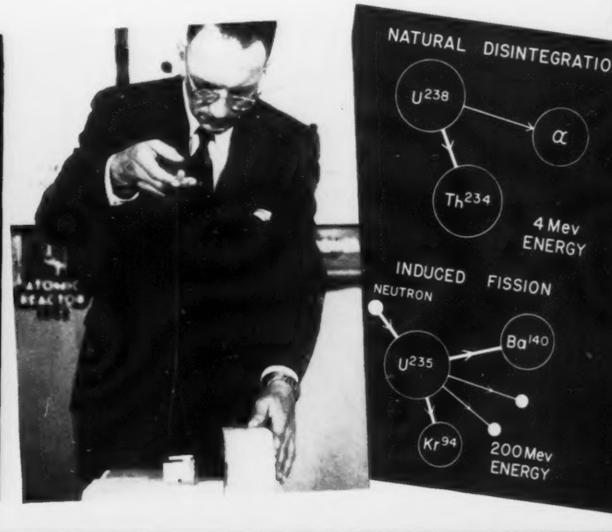
Purity of Substances. Before reliable physical and chemical properties can be established for a material, a knowledge of its purity is necessary. For example, the freezing point of a pure substance is lowered when other substances (impurities) are added, and this fact is basic for extremely precise purity measurements. Such methods—known as "cryoscopic"—are of two principal kinds: (1) the calorimetric and (2) the freezing-curve methods.

In the first method, the equilibrium melting temperatures are determined for various liquid-solid ratios which result from the addition of known amounts of heat. In the other method, a freezing or melting curve is obtained as the sample is progressively frozen or melted while the solid and liquid phases are kept in equilibrium by stirring. In this exhibit, the freezing curve procedure for measuring the purity of highly reactive substances was demonstrated. The freezing point of a high purity sample was determined. Also, a special display demonstrated visually the manner in which crystal growth in a solution lowers the freezing temperature of the remaining liquid.

FOSDIC: High-Speed Search of Data on Microfilm. The ever increasing use of statistical methods—in Government administration, in industrial quality control, in agricultural research, and in the physical sciences—has been encouraged by the development of new methods of mathematical analysis and high-speed devices for numerical computation.

Below, left: In this demonstration, the production of free radicals and their storage at low temperatures was exhibited to the lay public for the first time. Nitrogen molecules (N_2) are split into free radicals by an electric field in the intake tube. Then the molecular fragments solidify near the bottom of the central cylinder at a temperature just a few degrees above absolute zero. The frozen mass of free radicals glow a bluish-green, with an occasional brighter flash as the fragments recombine into normal nitrogen molecules. Energy stored as free radicals is one of the most concentrated forms of chemical energy yet discovered. _Below, right:_ A neutron source is lowered into a paraffin block containing small amounts of uranium preparatory to an experiment in nuclear fission. When a neutron strikes a uranium nucleus it causes it to split, giving off a burst of energy. Energy bursts were detected with a proportional counter whose output was made visible as pips on an oscilloscope screen. The large pips produced by uranium fission contrasted strikingly with the smaller ones due to the natural radioactivity of the uranium. By inserting a cadmium screen between the neutron source and the uranium, a noticeable decrease occurred in the number of fission pips, thus illustrating the way in which a nuclear reactor is controlled.





As a result, there is a persistent demand for more efficient ways of storing and processing large quantities of information. Among other things that the Bureau has done to meet this need is its development of FOSDIC—a Film Optical Sensing Device for Input to Computers.

FOSDIC has been designed to scan or search optically a microfilm file, to select electronically the required information, and to record it in a suitable form for automatic analysis.

Two models of this instrument have been developed at NBS, FOSDIC I for the Bureau of the Census and FOSDIC II for the Weather Bureau. FOSDIC I scans census records, recovers all data, and prepares a magnetic tape for use in an electronic computer. FOSDIC II searches punched-card weather records and automatically selects and reproduces desired cards for subsequent weather analysis.

Standards for Good Measure. Application of the standards of length and mass to accurate measurements has played an essential part in the industrial growth of the Nation.

Its importance extends, in fact, to every section of the economy—to the agencies of production, processing, and manufacture, to the channels of trade, and to purchasers of commodities and services.

The Congress has left to the individual States the responsibilities for regulating commercial transactions involving quantity; but responsibility for establishing and maintaining the *standards* of measurement are reserved to the Federal Government.

The Bureau, by its advisory services, cooperates with the States in promoting efficient weights and measures supervision through uniform laws, standards, methods of inspection, and administrative procedures. In this way the national standards are translated into everyday use.

Fire Resistance of Building Elements. Practically all buildings, from small houses to large warehouses and skyscrapers, have combustible contents that represent fire hazards. To prevent flames from spreading too rapidly, municipal codes require that building elements resist fire for specified periods of time. This is to give occupants and contents, even in remote parts of a building, sufficient time to reach safety.

Measurement of the fire resistances of building elements has been obtained from large scale fire tests conducted according to a widely accepted method. The results have been published for the information of building code officials, architects, and engineers.

However, a single large-scale fire test requires considerable material, time, and energy.

It is highly desirable, therefore, to have some procedure for obtaining rapid and reasonably accurate predictions of fire endurance when experimental results are not immediately available.

To meet this problem, the Bureau has developed a transient heat-flow analyzer of electrical type which makes use of thermal properties of materials to predict the heat flow through building elements. For those cases where the limiting condition is temperature rise due to heat flow to the unexposed surface of the specimen, this prediction can be converted into an estimate of the fire resistance.

Shock Loading of Textiles. One of the demands made on fibrous materials used in equipment for industry, public safety, and national defense is the ability to withstand very high-speed impacts. For example, aircraft landing shock must be absorbed in part by textile tire cords. Similarly, impact forces must also be withstood by automobile and truck tire cords.

Another example is the thread used in industrial sewing which must stitch efficiently without breaking under strains repeated 5,000 times per minute. Parachute harnesses, webbing, and shroud lines must take the brunt of high impact forces of opening shock after pilot ejection from high-speed airplanes. Still another example is the flexible body armor that must protect military personnel from exploding shell fragments.

Part of the Guest Week exhibit of research on shock loading of textiles. Results of such studies are applied, for example, in designing parachute harnesses and safety belts that will better withstand suddenly applied forces. Guests were shown high-speed motion pictures (made with equipment at left), with which the effects of sudden forces on individual textile fibers can be traced in detail.

As its part in meeting this problem, the Bureau is assisting industry and Government to solve the basic technical and scientific difficulties in the development, production, and establishment of specifications for fibrous materials. Special precision equipment, utilizing high-speed photography, has been built for measuring properties of fibers, yarns, and fabrics under shock loading.

Forces and Their Effects. If our bridges, buildings, aircraft, and other structures are to be safe and economical in the use of materials, an accurate knowledge of the material properties is required.

Such knowledge is gained from tests on components, or full scale structural units, or models.

The accuracy of equipment which is used in such tests depends on the precise measuring standards for force and deformation maintained by the Bureau.

Bureau facilities include unique equipment such as deadweight testing machines, proving rings, compres-

sion dynamometers having capacities as great as 3 million pounds, and the world's largest compression testing machine of 10 million pounds capacity.

Industry and Government rely on the Bureau's calibration service to check the accuracy of dynamometers for measuring the thrust of jet engines and rockets, and for weighing objects ranging from airplanes to the contents of bins and hoppers.

Electronic Computers. High-speed electronic computers for automatic data processing are being rapidly applied to more and more of the complex mathematical problems arising in research. These machines solve in minutes problems that would require weeks or months of laborious hand calculations, or that might not even be undertaken at all. High-speed data processors are also widely used in business to make up payrolls, keep track of inventories, evaluate bids, and to perform many other tasks where massive amounts of paper-work must be expedited.

The NBS machines are of both digital and analog types. The problems solved include the computing of mathematical tables, the relative abundance of the chemical elements, rocket paths, optical lens design, and problems arising in the development of military items. SEAC, the Standards Electronic Automatic Computer, is of the digital type. That is, it uses long trains of electrical impulses corresponding to the numbers in the problems. Analog computers give solutions in graphical form.

Numbers, Tables, and Answers. The Bureau's centralized computing facility is equipped with the most up-to-date calculating equipment available. This facility serves the needs of the Bureau's own diverse research programs and supplements the facilities of other government agencies and government contractors.

An historical presentation showed the significant progress in the development of computing equipment. The earliest digital computer, the abacus, stands in contrast to the present-day electronic digital high-speed computing machine, which combines a vast number of simple operations into a complex high-speed sequence and thus turns out the answers to many difficult computational and statistical problems. The functions of the Bureau in this area were illustrated by samples of published mathematical tables and by charts of problems solved on these machines.

Water Waves. The physical laws governing the growth and decay of water waves have long been of importance to naval architects in designing ships, and to engineers in designing shore and harbor structures.

A continuing research program at the Bureau has shed new light on these physical laws and has provided a means for estimating the magnitude of wind-generated waves and tides.

Two types of water waves, wind generated waves the solitary waves, were demonstrated.

Using a 100-foot channel, the development and growth of wind waves and the associated wind tide were shown. Their action on a layer of colored salt water was also visible.

The method used to generate this unusual wave form was demonstrated in an 80-foot solitary-wave tank. Its application in investigating the forces exerted by water waves on submerged structures was also shown.

On display were methods by which the wave forces and characteristics are measured and recorded.

Volts, Ohms, and Amperes. Measurement is vital to the 30-billion-dollar yearly sale of electric energy and equipment. For example, it assures the householder of the accuracy of the electric meter on which his monthly bills are based, and it enables manufacturers to make accurate resistors and coils for use in television sets.

Such measurement is based on the fundamental electrical standards which the Bureau has established and maintained and uses to calibrate master standards for universities, private laboratories, manufacturers, utilities, and regulatory agencies.

The basic standards are known to a few parts in 1 million; an accuracy of about 3 parts in 10 thousand (0.03%) is achieved in the Bureau's standard watthour meter by which the master standards of the public utility commissions and power companies are calibrated. In turn their measurements are made to about 0.1 percent so that the accuracy of the meter in one's home is better than 1 part in a hundred. Many other kinds of standards are needed to meet the requirements of modern technology for measuring power, voltage, current, resistance, and other electrical quantities.

Rapid Spectrochemical Analysis. Any material when vaporized in an electric arc or spark gives off light whose wavelengths are characteristic of the chemical elements present. When this light is passed into a spectrograph, the wavelengths are spread apart into the familiar rainbow colors known as a spectrum. By observing which wavelengths are present, one can learn which elements, such as iron, manganese, or copper, the material contains. The brightness or intensity of spectral lines, relative to intensities obtained from standard samples, tells how much of each element is present. Spectrometric analysis can be made on samples of almost any size or form, from microscopic particles to massive pieces or solutions. Examples of the standard samples were shown and their use described.

A recent development in this field is the use of the X-ray spectrum as a means of making more precise analyses, particularly for complex alloys such as those used in jet aircraft and rockets. A new X-ray spectrometer showed how the determination of 7 elements is made in a stainless steel sample in about 1 minute.

Measurements at High Temperatures. There is an urgent need for substances that can withstand temperatures above 2,000° C (3,600° F). To provide scientists and engineers with information about materials suitable for use in jet planes, rockets, guided missiles, earth satellites, and nuclear reactors, one must learn how various materials stand up under the tremendous heats generated.

The immediate task is not necessarily to develop new refractory materials by trial and error. Rather, it is more a problem of precise measurement of the

physical and chemical properties of already existing materials at these high temperatures. To obtain such basic data more easily and accurately, the Bureau is developing new ways to carry out experiments at high temperatures.

Some special devices used in the program were shown in this exhibit: a vacuum chamber microbalance to determine the relative volatility of solids at high temperature; a differential thermal analysis apparatus to study the thermodynamic changes that occur in crystalline transformations of alumina, silica, and other oxides; and a sonic measurements furnace to determine elastic and strength properties of refractory substances.

The Bureau's long-range program for obtaining precise quantitative data on inorganic materials which are most stable at high temperatures should lead to a better understanding of the chemistry and physics of refractories.

Solar Energy Furnace and High-Pressure Reaction Chamber. The further development of equipment such as jet engines and nuclear power plants is seriously limited by a lack of materials that can withstand high temperatures and pressures. Such requirements are already out of the range of most metals and even beyond the strength and refractoriness of ceramics. It has been necessary, therefore, to make fundamental studies of the physical and chemical stability of ceramic oxides, silicides, and non-oxide substances under extreme conditions.

This field of investigation presents many problems not found at more ordinary temperatures and pressures. Unpredictable complex molecules may be formed; or complete reversal of a compound's normal properties may occur. Atomic structure, too, can be rearranged, resulting in new and different properties. Also, minute traces of impurities can produce profound effects on materials at extreme temperatures and pressures.

To investigate these unusual effects the Bureau has a special laboratory where a solar energy furnace can generate heat up to 4,000° C (7,000° F)—two-thirds as hot as the surface of the sun. In addition, a high pressure reaction chamber is used to synthesize certain minerals in their purest form. Pressures up to 1 million pounds per square inch and temperatures up to 1,500° C (2,700° F) can be generated. In this way it has been possible to make several artificial minerals that are more durable than their natural counterparts.

Structural Elements: Their Strength and Performance. People are so accustomed to living and working in buildings that few give thought to the safety of the structure they are occupying. That they are able to do so is a tribute to the skill and integrity of designers, engineers, and builders.

However, in order to design safe and economical structures, architects and engineers must know the properties of building materials and of structural elements. Much knowledge of this kind is obtained in the Bureau's structural engineering laboratories by actual tests of building components. Among the components tested are beams, slabs, walls, and columns. Assemblies of such components are also tested.

The information thus obtained provides Government and industry the means of establishing satisfactory specification and code requirements governing the performance of structural elements under various service conditions.

In evaluating the performance of structural elements, procedures must be followed that conform to the basic requirements of all reliable measurement methods—i. e., they must be reproducible and accurate.

In fact, an important phase of the work in the structural engineering laboratories deals with the development of methods for perfecting existing test procedures and with the devising of new techniques and methods for evaluating building construction.

Instruments for Research. Every scientific laboratory must have its instrument shop. Because the Bureau is involved in the most careful experimentation and measurement, its instrument shop is called on to produce equipment of the highest quality and precision.

Moreover, to meet the exacting demands of the Bureau's extensive and diverse research programs, its skilled instrument makers must have at their command the full range of techniques required in all branches of the physical sciences and engineering.

One of the interesting methods which could be seen in operation at the NBS instrument shop was the modern technique of glassblowing, including the use of the new glassblowing lathes. For measuring the accuracy of machined parts, an array of advanced equipment is used—for example, the Probograph, a three dimensional electromechanical measuring machine.

Another application of recent advances in science to the art of the instrument builder is the process of ultrasonic cavitation, which makes use of sound waves above the audible range for high-speed precision drilling.

Crystals and Corrosion. Wherever metals are used, corrosion presents its threat to economy and efficiency. Although much has already been done to control its damaging effects, corrosion is still estimated to cost this country more than 5 billion dollars annually.

The Bureau's contribution to solving this problem consists principally of attempts to determine the fundamental causes of corrosion and special studies of the corrosion resistance of specific alloys and types of alloys. Of special interest is the influence of metal structure on tarnishing and attack by acids and alkalies. Metals are generally made up of many small crystals—small units within which the atoms are arranged in perfectly ordered fashion. Instead of working with ordinary metals whose crystals are jumbled up haphazardly, the Bureau is studying large single crystals. It is found that when an aluminum single crystal is corroded, different symmetrical shapes develop depending on whether the attacking substance is acid or alkali. It is also found that when a copper single crystal is heated in oxygen, beautiful symmetric patterns of tarnish colors are formed on its surface. Thus, the results indicate that degree of corrosion depends on atomic arrangement on the surface.

Parity in Nuclear Physics. "Parity" is a concept of theoretical physics that deals with mirror reflection. This exhibit illustrated the meaning of parity by showing what happens to two common objects when they are

reflected in a mirror. We shall say, for instance, that a sphere is associated with a "definite parity" because it is indistinguishable from its image. However, because we can easily tell a screw from its image, we shall say that a screw is not associated with a definite parity.

For the last three decades theoretical physicists have assumed that all the basic particles that compose the nuclei of atoms were "spherelike", that is, they had definite parity. Furthermore, every process involving these particles was assumed to be indistinguishable from its mirror image. A year ago these assumptions were challenged by the theoretical physicists T. D. Lee of Columbia University and C. N. Yang of the Institute for Advanced Studies at Princeton, who also suggested several experiments to prove or disprove their contention. The Bureau undertook one of these experiments in collaboration with Columbia and last January results were obtained which verified the Lee-Yang hypothesis. This exhibit explained the Bureau experiment in terms of the sphere and screw models, showing how nature has given "screwlike" properties to certain nuclear reactions.

A transient heat-flow analyzer, an analog computer developed by the Bureau to avoid costly large-scale fire tests, was exhibited to students during Guest Week. To show the difficulties of an actual fire test, a relatively small sample of building material was burned (partly visible at left). The analyzer, on the other hand, can predict how a material will behave under conditions of actual combustion by calculations using data on thermal properties of the material. In particular, it predicts how fast flame will travel through the material—an important factor in fire safety.

Flames and Their Light. Some of first great advances in science are connected with the study of combustion. Today scientists are pushing this study down to its finer details and are investigating the atomic and molecular changes that give rise to flames.

The Bureau is interested in this problem because of the need to control the rate of burning and amount of energy released in the various flames found in such equipment as rockets and internal combustion engines.

This requires a thorough knowledge of the mechanism of combustion, and makes it necessary to develop ways to measure temperatures of flames that are too hot for ordinary thermometers.

One way to study flames is to analyze their light. This tells what molecules are present in the flame, and gives information about how energy is released in it.

A very useful technique is to study the light from flames at very low pressures such as a rocket encounters at high altitudes. Under such conditions the processes that generate light can be studied in greater detail, and reactions with atoms normally present 60 miles up in the atmosphere can be reproduced.

Knock Rating for Automotive Fuels. An important factor in the "matching" of engines and fuels is the octane number. Because of the trend toward higher-compression engines in the automotive industry, as well as aviation requirements, high octane numbers are increasingly important.

The National Standards for measuring octane number are two hydrocarbons (normal heptane and isooctane) which were synthesized and purified to a high degree in NBS laboratories. Ultimately, the quality of all the gasoline sold, at the rate of about 2 million gallons per hour, is referred to the National Standards.

As the continuing development of engines and fuels brings new problems, researches are conducted to improve the precision of measurement, raise the quality of the fuel standards, and to study the mechanism of fuel combustion as well as the effects of such variables as altitude, temperature, and humidity.

The Bureau has played an important part in the study of the relationship between the knocking characteristics of gasoline constituents and their molecular structure. These studies provide a background of information useful in maintaining the standards.

Plastics. Each year the use of plastics in the home and in industry increases. The ease of processing as well as the performance of these materials add to their utilization in many diverse applications. Plastics are made by uniting many small chemical units, known as monomers, into a long chain or network structure which is called the polymer. The chemical nature of the monomer and the structural arrangement of the polymer chains determine the physical and chemical properties of the plastic material which can be shaped and molded into intricate forms.

The Bureau cooperates in the development of standards and specifications for these materials, of which there are potentially an almost unlimited number. It also devises methods for determining the properties of these new materials and investigates the basic mechanisms responsible for the properties. For example, the mechanisms by which plastics break down on exposure to sunlight, heat, oxygen, moisture, and nuclear radiation are studied to determine the relationship between chemical structure and durability.

[1] Solar furnace (*p. 101 of this issue*).

[2] Reversal of parity law in nuclear physics, *NBS Tech. News Bul.* **41**, *56* (*April 1957*).

[3] Low-temperature storage of free radicals, *NBS Tech. News Bul.* **40**, *112* (*Aug. 1956*); *see also* Free radicals research program, *NBS Tech. News Bul.* **41**, *1* (*Jan. 1957*).

[4] Radiation balance, *NBS Tech. News Bul.* **39**, *1* (*Jan. 1955*).

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NATIONAL BUREAU OF STANDARDS
A. V. ASTIN, *Director*

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Contents

Publications of the National Bureau of Standards

Journal of Research of the National Bureau of Standards, Volume **58**, No. 6, June 1957 (RP2762 to RP2767 incl.), 60 cents. Annual subscription $4.00.

Technical News Bulletin, Volume **41**, No. 6, June 1957. 10 cents. Annual subscription $1.00.

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RP2763. Emission spectra of actinium. William F. Meggers, Mark Fred, and Frank S. Tompkins.

RP2764. Thermal design of large storage vessels for liquid hydrogen and helium. Russell B. Scott.

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RP2766. A nonlinear instrument diaphragm. Fidel Cordero, Harry Matheson, and Daniel P. Johnson.

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